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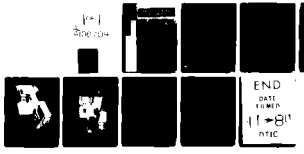

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A Report to

Air Force Office of Scientific Research

from

THERMOPHYSICAL PROPERTIES RESEARCH LABORATORY
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The specific heat of a fine weave and of a course weave carbon/carbon composite was measured from 340 to 750 K and compared to the values obtained on a POCO graphite. These results, added to previously obtained results at higher temperatures measured at NBS show that the specific heat of carbon/carbon composites is equal (within 1%) of that of graphite above 340 K. These results are valuable as they permit conversion of thermal diffusivity data to thermal conductivity results.

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(R. E. Taylor)
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SPECIFIC HEAT OF CARBON/CARBON COMPOSITES

INTRODUCTION

Several laboratories are measuring thermal diffusivity "α" of carbon/carbon composites and converting these results to thermal conductivity "λ" using the relation $\lambda = \alpha C_p \delta$ where δ is the bulk density and C_p is the specific heat. It has been customary to assume that specific heat values for graphites are applicable to these composites. However, there has been some question as to the validity of this assumption, especially near room temperature. Therefore the present work was undertaken with the aim of obtaining reasonably accurate (within 2%) specific heat values of several carbon/carbon composites from 340 to 750 K and to compare the results with those for POCO graphite AXQ-5M obtained from the National Bureau of Standards.

A Perkin-Elmer model DSC-2 Differential Scanning Calorimeter (Figure 1) was used. This DSC is connected to a minicomputer-based digital data acquisition system (Figure 2) which collects the data and computes the results at 5 °K intervals. A copy of the initial portion of the computer output for a fine weave C/C composite is shown as Table 1.

The fine weave carbon/carbon was fabricated by Fiber Materials, Inc. The sample is from Billet F 25 G B1. The fibers were Hercules Hm 1000 and 3000 PAN. The matrix was Ashland 15V coal tar pitch. The filament properties are as follows:

	Hm 1000	Hm 3000
Yarn precursor: Polyacrylonitrile filaments/yarn	1000	3000
Fiber type: Graphite		
Cross-section: Round		
Bulk density: 1.80-1.88 g/cm^{-3}		

The composite sample description is as follows:

	X	Y	Z
Number of fibers	2(HM 1000)	2(HM 1000)	1(Hm 3000)
Number of filaments	2000	2000	3000
Fiber volume fraction	13%	13%	22%
Spacing	0.033"	0.033"	0.030"
Bulk density	1.883 g/cm^3		
Maximum processing temperature	2750 °C		
Billet open porosity	4.7%		

The course weave carbon/carbon was fabricated by the Jet Propulsion Laboratory and was designated as HEPN-1. It is an AVCO Radially-Pierced Fabric^{TM} made from T300 rods and fabric and processed to an average density of 1.9 g/cm^{-3}.

RESULTS AND DISCUSSION

The average results at 25 °K intervals (i.e., 20% of the data) are given in Table 2 and plotted in Figure 3. The coefficients for least square cubic equations

$$C_p \text{ (Ws gm}^{-1} \text{ K}^{-1}) = A + BT + CT^2 + DT^3$$

where T is in K are given in Table 3 along with the standard and maximum deviations. The equations fit the experimental data well within 1% except for POCO graphite at 340 K where the fit is 1.4%. Using these equations, the results for the four samples are intercompared in Table 4 for the temperature range 350 to 750 K. The maximum deviation of any of the samples from the average is 0.6% (course weave, outer at 475 K). Since the absolute accuracy as determined by measuring a sapphire standard as a sample at the same time was 1%, the comparison shows that the specific heat values of all four samples are indistinguishable, experimentally.

At higher temperatures, it would be expected from solid state theory that the specific heat of graphite and carbon/carbon composites would be close together. Indeed the specific heat results of Cezairliyan [1] and Cezairliyan and Righini [2] for POCO graphite and Cezairliyan and Miiller [3] for a General Electric fine weave carbon/carbon composite were within two percent of each other from 1500 to 3000 K. The present results can be joined smoothly to these curves so it is concluded that the specific heat of carbon/carbon composites is the same as that of POCO graphite and that the values are known within 3 percent from 340 to 3000 K.

A fifth degree polynomial equation which fits the combined POCO specific heat data of Taylor and Groot [4], the present results and the Cezairliyan [1,2] results with a standard deviation of 0.0523 and a maximum of 0.0199 W sec $gm^{-1}K^{-1}$ is

$$C_p = -0.3960843 + 0.47482055 \times 10^{-2}\, T - 0.38883733 \times 10^{-5}\, T^2 + $$
$$+ 0.16555666 \times 10^{-8}\, T^3 - 0.35301095 \times 10^{-12}\, T^4 + 0.29840058 \times 10^{-16}\, T^5.$$
$$340 \leq T \leq 3000 \text{ K}$$

TABLE 1

COPY OF INITIAL PORTION OF COMPUTER PRINTOUT

(FINE WEAVE C/C)

RESULTS

Sample Weight: 0.036200

Standard Weight: 0.060500

Temperature (K)	Temperature (F)	Sample Amplitude	Standard Amplitude	Blank Amplitude	Specific Heat (Joule $gm^{-1} K^{-1}$)	Specific Heat (BTU $lb^{-1} F^{-1}$)
340	152	-.92736E-02	-.17308E-01	.13676E-02	.81110	.19386
345	161	-.94945E-02	-.17609E-01	.13593E-02	.82256	.19660
350	170	-.97480E-02	-.17931E-01	.13566E-02	.83528	.19964
355	179	-.10035E-01	-.18291E-01	.13605E-02	.84885	.20288
360	188	-.10368E-01	-.18599E-01	.13738E-02	.86835	.20754
365	197	-.10642E-01	-.18965E-01	.13585E-02	.87956	.21022
370	206	-.10873E-01	-.19118E-01	.13584E-02	.89716	.21443
375	215	-.11133E-01	-.19241E-01	.13349E-02	.91769	.21933
380	224	-.11116E-01	-.19237E-01	.13409E-02	.92381	.22080
385	233	-.11139E-01	-.19402E-01	.13620E-02	.92566	.22124
390	242	-.11277E-01	-.19525E-01	.13898E-02	.93806	.22420
395	251	-.11415E-01	-.19592E-01	.14163E-02	.95274	.22771
400	260	-.11555E-01	-.19710E-01	.14552E-02	.96550	.23076
405	269	-.11693E-01	-.19796E-01	.14944E-02	.97962	.23414
410	278	-.11830E-01	-.19880E-01	.15379E-02	.99348	.23745
415	287	-.11970E-01	-.19976E-01	.15809E-02	1.00696	.24067
420	296	-.12079E-01	-.20062E-01	.16365E-02	1.01881	.24350
425	305	-.12203E-01	-.20230E-01	.16656E-02	1.02721	.24551
430	314	-.12322E-01	-.20316E-01	.17111E-02	1.03914	.24836
435	323	-.12434E-01	-.20381E-01	.17542E-02	1.05142	.25130
440	332	-.12536E-01	-.20485E-01	.18050E-02	1.06111	.25361
445	341	-.12655E-01	-.20567E-01	.18627E-02	1.07325	.25651
450	350	-.12760E-01	-.20618E-01	.19144E-02	1.08540	.25942
455	359	-.12864E-01	-.20648E-01	.19725E-02	1.09879	.20262
460	368	-.12962E-01	-.20710E-01	.20009E-02	1.10898	.26505
465	377	-.13058E-01	-.20779E-01	.20380E-02	1.11897	.26744

TABLE 2

SPECIFIC HEAT RESULTS

Temp. (°K)	Temp. (°F)	POCO		Fine Weave		Course Weave (outer)		Course Weave (inner)	
		(†)	(*)	(†)	(*)	(†)	(*)	(†)	(*)
340	152	0.8283	0.1980	0.8111	0.1939	0.8181	0.1955	0.8179	0.1955
350	170	0.8428	0.2014	0.8383	0.2004	0.8425	0.2014	0.8432	0.2015
375	216	0.9023	0.2157	0.9112	0.2178	0.9143	0.2185	0.9129	0.2182
400	260	0.9705	0.2320	0.9667	0.2310	0.9657	0.2308	0.9703	0.2319
425	305	1.0293	0.2460	1.0261	0.2452	1.0226	0.2444	1.0307	0.2463
450	350	1.0868	0.2598	1.0810	0.2584	1.0806	0.2583	1.0897	0.2604
475	395	1.1485	0.2745	1.1364	0.2716	1.1333	0.2709	1.1464	0.2740
500	440	1.1950	0.2856	1.1889	0.2842	1.1831	0.2828	1.1983	0.2864
525	485	1.2423	0.2969	1.2372	0.2957	1.2316	0.2944	1.2500	0.2988
550	530	1.2866	0.3075	1.2815	0.3063	1.2770	0.3052	1.2924	0.3089
575	595	1.3258	0.3169	1.3242	0.3165	1.3207	0.3157	1.3298	0.3178
600	620	1.3622	0.3256	1.3617	0.3255	1.3654	0.3263	1.3701	0.3275
625	665	1.3979	0.3341	1.3990	0.3344	1.4004	0.3347	1.4021	0.3351
650	710	1.4316	0.3422	1.4366	0.3434	1.4393	0.3440	1.4399	0.3441
675	755	1.4666	0.3505	1.4689	0.3511	1.4673	0.3507	1.4721	0.3518
700	800	1.5143	0.3619	1.5150	0.3621	1.5265	0.3648	1.5257	0.3647
725	845	1.5441	0.3690	1.5449	0.3690	1.5453	0.3693	1.5491	0.3702
750	870	1.5793	0.3775	1.5773	0.3770	1.5781	0.3772	1.5802	0.3777

(*) BTU lb^{-1} F^{-1} = cal gm^{-1} K^{-1}

(†) Ws gm^{-1} K^{-1} = J gm^{-1} K^{-1}

TABLE 3

COEFFICIENTS FOR LEAST SQUARE CUBIC EQUATIONS

Sample	A	B	C	D	Std. Dev.	Max. Dev.
POCO	-0.693351E+00	0.638108E-02	-0.672955E-05	0.301132E-08	0.56330E-02	0.11662E-01
Fine-Weave	-0.640773E+00	0.601223E-02	-0.599403E-05	0.256241E-08	0.29116E-02	0.56866E-02
Course-Weave (Outer)	-0.398888E+00	0.467623E-02	-0.363979E-05	0.123026E-08	0.46838E-02	0.13543E-01
Course-Weave (Inner)	-0.697153E+00	0.632387E-02	-0.646827E-05	0.278292E-08	0.49083E-02	0.11052E-01

TABLE 4

STATISTICAL COMPARISON

Sample List

1 POCO
2 Fine Weave
3 Course Weave (Outer)
4 Course Weave (Inner)

Temp.	Average	Standard Deviation	Maximum Deviation	Sample with Max.	Minimum Deviation	Sample with Min.
350	.8429E+00	.2292E-02	.3813E-02	2	-.2311E-03	4
375	.9093E+00	.2504E-02	.3267E-02	2	.1580E-02	3
400	.9719E+00	.3427E-02	.3955E-02	3	.2845E-02	2
425	.1031E+01	.4184E-02	.5495E-02	3	.2532E-02	2
450	.1087E+01	.4625E-02	.6308E-02	3	.2312E-02	2
475	.1139E+01	.4764E-02	.6505E-02	3	.2171E-02	2
500	.1189E+01	.4653E-02	-.6324E-02	4	-.1961E-02	1
525	.1236E+01	.4357E-02	-.6336E-02	4	-.1208E-02	1
550	.1281E+01	.3951E-02	-.6158E-02	4	-.3874E-03	1
575	.1324E+01	.3514E-02	-.5825E-02	4	.4418E-03	1
600	.1364E+01	.3122E-02	-.5374E-02	4	.1224E-02	1
625	.1403E+01	.2834E-02	-.4843E-02	4	.8612E-03	3
650	.1441E+01	.2658E-02	-.4265E-02	4	-.1967E-03	3
675	.1477E+01	.2535E-02	-.3678E-02	4	-.9954E-03	3
700	.1512E+01	.2372E-02	-.3119E-02	4	-.1428E-02	3
725	.1546E+01	.2068E-02	-.2622E-02	4	-.1383E-02	3
750	.1579E+01	.1582E-02	-.2224E-02	4	-.7508E-03	3

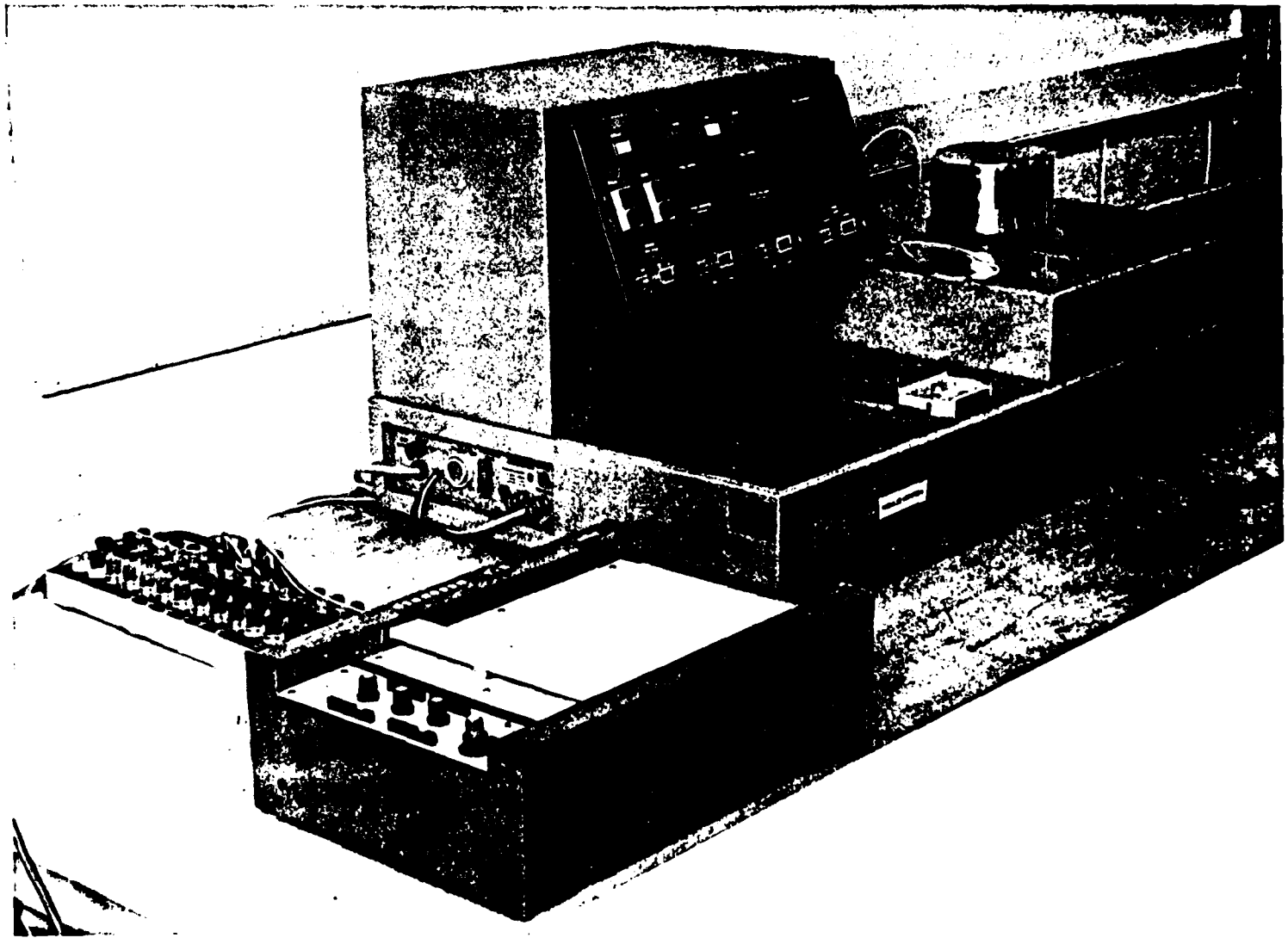

FIGURE 1

PERKIN-ELMER DIFFERENTIAL SCANNING CALORIMETER

FIGURE 2

DIGITAL DATA ACQUISITION SYSTEM

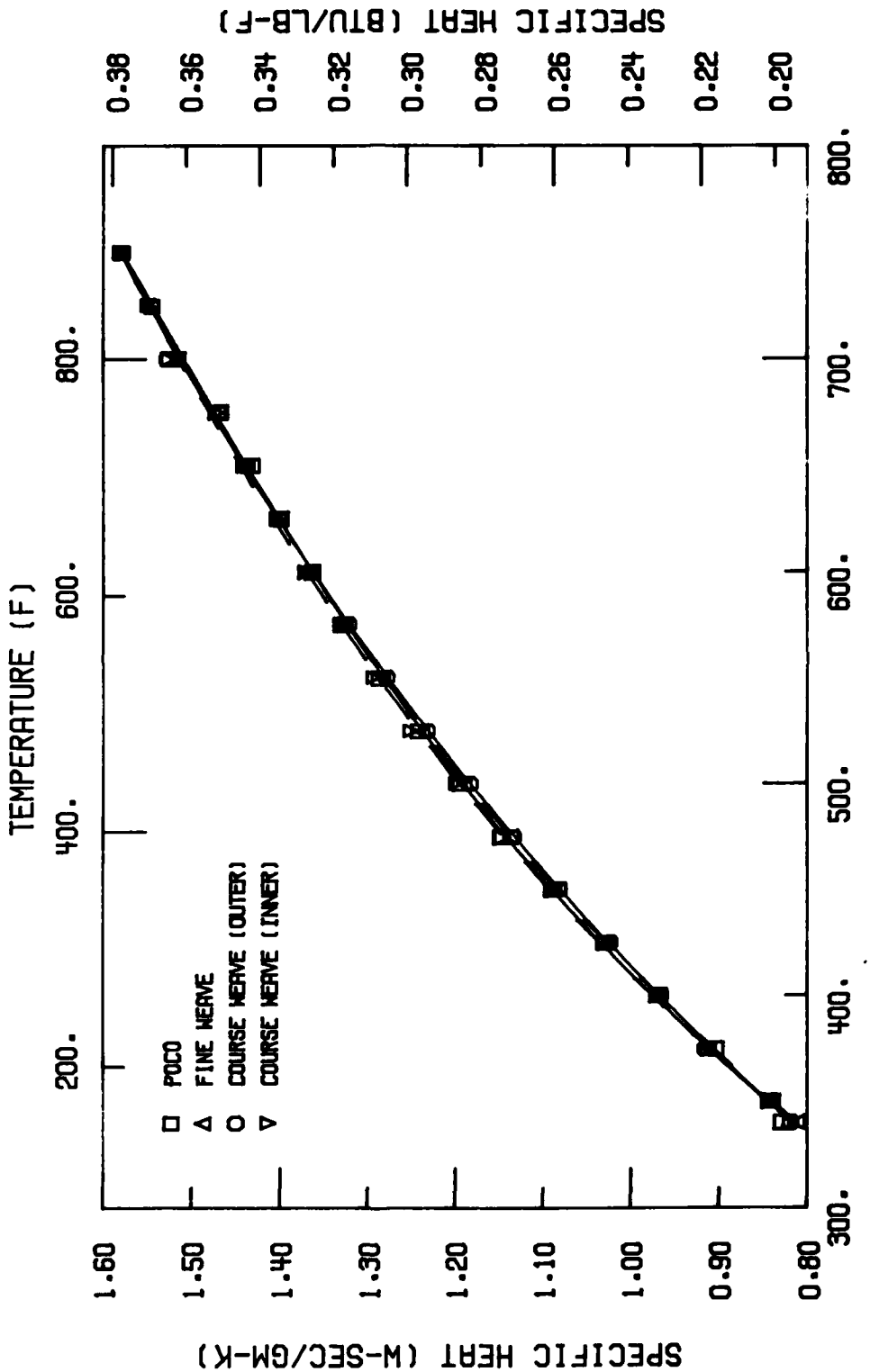

FIGURE 3

SPECIFIC HEAT RESULTS

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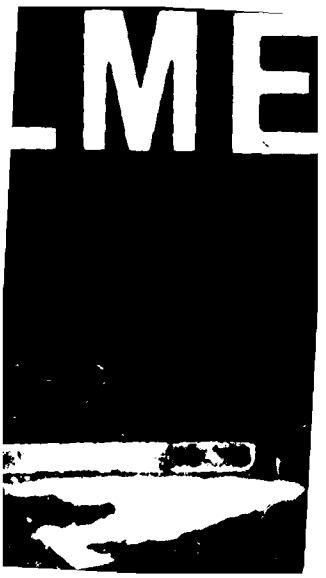
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